THE ENERGY COST OF SOME FORMS OF PHYSICAL ACTIVITY OF NINE-YEAR-OLD GIRLS

DISSERTATION

Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy under
the Joint Committee on Graduate Instruction, Columbia University in the City of
New York

BY

MARTHA POTGIETER

New York City
1933

Digitized by the Internet Archive
in 2017 with funding from
This project is made possible by a grant from the Institute of Museum and Library Services as administered by the Pennsylvania Department of Education through the Office of Commonwealth Libraries

https://archive.org/details/energycostotsome00potg

ACKNOWLEDGMENTS

This study was undertaken at the suggestion of Professors Mary S. Rose and Grace MacLeod, to whom the author wishes to express her appreciation of helpful advice and suggestions. Especially to Professor MacLeod, under whose direction the study was carried out, is the author deeply indebted for unstinted counsel, assistance, and encouragement at all stages of the work.

THE ENERGY COST OF SOME FORMS OF PHYSICAL ACTIVITY OF NINE-YEAR-OLD GIRLS

INTRODUCTION

The caloric cost of exercise was first demonstrated by Lavoisier. In 1789 he and his co-worker, Seguin,[1] found the oxygen consumption of a man in the post-absorptive state to be increased about 40 liters per hour, or 176 per cent, by the work of lifting and lowering a weight. Not until about the middle of the nineteenth century were any further investigations carried out in this field. Smith,[2] in 1859, determined the increase in carbon dioxide production during walking over that while sitting quietly, and found it to be 143 per cent while walking at the rate of two English miles an hour and 247 per cent while walking three English miles an hour. Pettenkofer and Voit,[3] in 1866, found the carbon dioxide of a man on a normal diet to be increased about 60 per cent by the work of turning a wheel. Forster,[4] in 1877, using Pettenkofer and Voit's respiration chamber, determined the carbon dioxide output of children while sitting quietly but not in basal condition. He found it to be more than twice as great, in grams per kilogram of body weight, as that of adults under similar conditions. Speck,[5] in 1881, in experiments carried out with a view to determining the variations due to age and sex under the same conditions of activity or rest, found that a ten-year-old girl, weighing 25.4 kilograms, while sitting quietly reading five hours after breakfast, consumed 172 cc. of oxygen per minute, and showed a respiratory quotient of 0.855. Interpreted in terms of Calories, this is about two Calories per kilogram of body weight per hour. Sondén and Tigerstedt[6] (1895) were the first to construct a large respiration chamber for such work. Their chamber had a volume of 100 cubic meters and their experiments were carried out on groups of six to eighteen children in periods usually one-half hour in length. In four one-half-hour experiments on six nine-year-old girls, in which the subjects were sitting quietly, eating candy and fruits, several hours after breakfast, the total carbon dioxide production was 59, 67, 69, and 76 grams, with an average of 68 grams, or 22.7 grams per individual per hour, or 0.85 grams per kilogram of body weight per hour.

For more than a quarter of a century after Sondén and Tigerstedt's work was reported there appeared nothing in the literature on the energy expenditure of children in any condition other than basal. In 1923 Bedale[7] published the results of an extensive study of the energy metabolism during exercise of the children in a private school in Hampshire, England. Forty-five boys and 55 girls, ranging in age from 5 to 18 years, served as subjects. Their carbon dioxide production and oxygen consumption were determined, by means of the Douglas bag, during all of the various activities of the school day, and the caloric cost of the activities calculated therefrom. Five girls between 9 and 10 years of age, with an average body weight of 28.2 kilograms, showed the following average energy expenditure (in Calories per kilogram of body weight per hour) during their various activities: basal condition, 1.49; gardening, 4.47; games, 6.30; walking, 4.66; in the school room, 2.04; weaving, 2.47; caring for animals, 4.21. The following table shows a typical daily program for these girls and their calculated daily food requirements:

Hours	Activity	Total Caloric Cost
12	In bed (6 hours at basal, 6 hours at basal plus 15 per cent)	541.4
2½	Meals, dressing, undressing	315.0
2	In school	140.4
1	Weaving	90.6
3	Gardening	450.6
½	Caring for animals	85.0
3	Outdoor play	600.0
	Total	2,223.0

From dietary studies their average daily food intake was found to be 2,468 available Calories. Deducting 1,000 Calories (24-hour basal metabolism) from this leaves 1,468 Calories to cover the needs of activity, growth, and the specific dynamic effect of food. Deducting the total calories expended from the calories consumed (2,468 — 2,223), we have an intake over the daily requirement of 245 Calories per day, which, the author concludes, are used up in growth.

Helmreich,[8] in 1925, by means of the Krogh spirometer, measured the energy cost, in children, of lifting the leg fifteen times a minute, for the purpose of determining whether the increase in energy metabolism produced by exercise is the same at different ages. He found the oxygen consumption per kilogram-meter of work performed to be the same for all ages ranging from three to fourteen years.

McClintock and Paisley[9] determined the cost in gram calories per kilogram-meter of horizontal walking in 65 boys and girls 11 to 14 years of age. The average cost for the boys was found to be approximately 0.64 and for the girls 0.59 gram calories per horizontal kilogram-meter. The authors compared the former figure with the cost of similar exercise in men, and found it to be 20 per cent higher. These investigators did not determine the basal metabolism of their subjects but used the figures from prediction tables for individuals of their ages. From a comparison of these predicted basal metabolic rates and the cost of walking as determined for these subjects with similar figures obtained by Benedict and his co-workers in Boston for men, these authors conclude that the cost of horizontal walking varies directly with the basal metabolic rate.

In only these few studies has any attempt been made to establish the cost of children's activities, and in only one of them was the activity compared directly with the basal metabolism of the individual. To obtain further knowledge in this important field the present investigation was undertaken, the object being to determine the energy expenditure of average, healthy nine-year-old girls during two different kinds of activity typical of children of this age, namely, quiet play while seated and stair-climbing. The caloric cost of maintaining the body in a state of complete inactivity at the same time of day and also in the morning before rising was determined. These figures were used as base lines in determining the cost of the activity alone.

PLAN OF THE INVESTIGATION

(a) **Subjects**

The subjects for this research were six healthy, nine-year-old white girls, born in the United States, living in a home for homeless children in New York City. Their variations in weight from the Baldwin-Wood[10] standards for their heights and ages ranged, at the beginning of the investigation, from —8.7 per cent to +7.5 per cent. During the course of the investigation these variations changed but little. Table I, page 8, shows their measurements at the beginning, middle, and end of the investigation with their variations from the standards at these times. Throughout this investigation the weights used were those determined on the date nearest the day of the test.

Not one of the subjects missed a day of school or a scheduled test in the respiration chamber during the period of the investigation because of colds or other illness, with the exception of a few days for tonsillectomy in the case of subjects one and two. Their cooperativeness, willingness, and interest in the work were very satisfactory. Their regular daily habits, enforced by the institution in which they lived and by their attendance at public school, aided in making them excellent subjects for research of this kind, where uniformity of subjects from individual to individual and of all individuals from day to day is desirable. All determinations were carried out on school days and at the same time of day, namely, between three and four in the afternoon, thus further insuring uniformity of conditions.

TABLE I.—HEIGHT AND WEIGHT OF SUBJECTS AT BEGINNING, MIDDL AND END OF PERIOD OF INVESTIGATION

Subject No.	Place of birth	Nationality of mother	Nationality of father	Age yr.-mo.	Weight kg.*	Height cm.	Normal weight for height and age†	Deviation from normal per cent	Surface area‡ sq. m.
						November 24, 1931			
1	U. S. A.	German	French	9- 6	27.0	129.3	27.7	—2.5	0.99
2	U. S. A.	Norwegian	English	9-10	28.2	134.9	30.9	—8.7	1.03
3	U. S. A.	Canadian	U. S.	9- 0	23.8	118.9	22.6	+5.3	0.89
4	U. S. A.	Puerto Rican and French	U. S.	9- 1	25.4	126.0	25.8	—1.5	0.95
5	U. S. A.	U. S.	U. S.	9- 5	27.3	125.2	25.4	+7.5	0.97
6	U. S. A.	German	U. S.	9-11	23.8	124.2	25.3	—5.9	0.92
	Average				25.9				
						March 9, 1932			
1	U. S. A.	German	French	9-10	27.8	129.5	27.8	0.0	1.00
2	U. S. A.	Norwegian	English	10- 1	29.1	135.1	31.1	— 6.4	1.06
3	U. S. A.	Canadian	U. S.	9- 4	25.2	119.6	22.8	+10.5	0.91
4	U. S. A.	Puerto Rican and French	U. S.	9- 5	27.3	126.3	26.0	+ 5.0	0.98
5	U. S. A.	U. S.	U. S.	9- 8	28.0	125.2	25.9	+ 8.1	0.98
6	U. S. A.	German	U. S.	10- 2	24.9	124.7	25.6	— 2.7	0.93
	Average				27.1				
						June 7, 1932			
1	U. S. A.	German	French	10- 1	29.7	132.3	29.3	+1.4	1.04
2	U. S. A.	Norwegian	English	10- 4	30.7	138.0	32.4	—5.2	1.09
3	U. S. A.	Canadian	U. S.	9- 8	25.8	122.4	24.4	+5.7	0.94
4	U. S. A.	Puerto Rican and French	U. S.	9- 9	27.7	129.2	27.7	0.0	1.00
5	U. S. A.	U. S.	U. S.	9-11	28.8	129.2	27.7	+4.0	1.02
6	U. S. A.	German	U. S.	10- 5	25.5	127.8	27.1	—5.9	0.97
	Average				28.0				

* In indoor clothing without shoes.
† From Baldwin-Wood Tables.[10]
‡ From DuBois chart.[11]

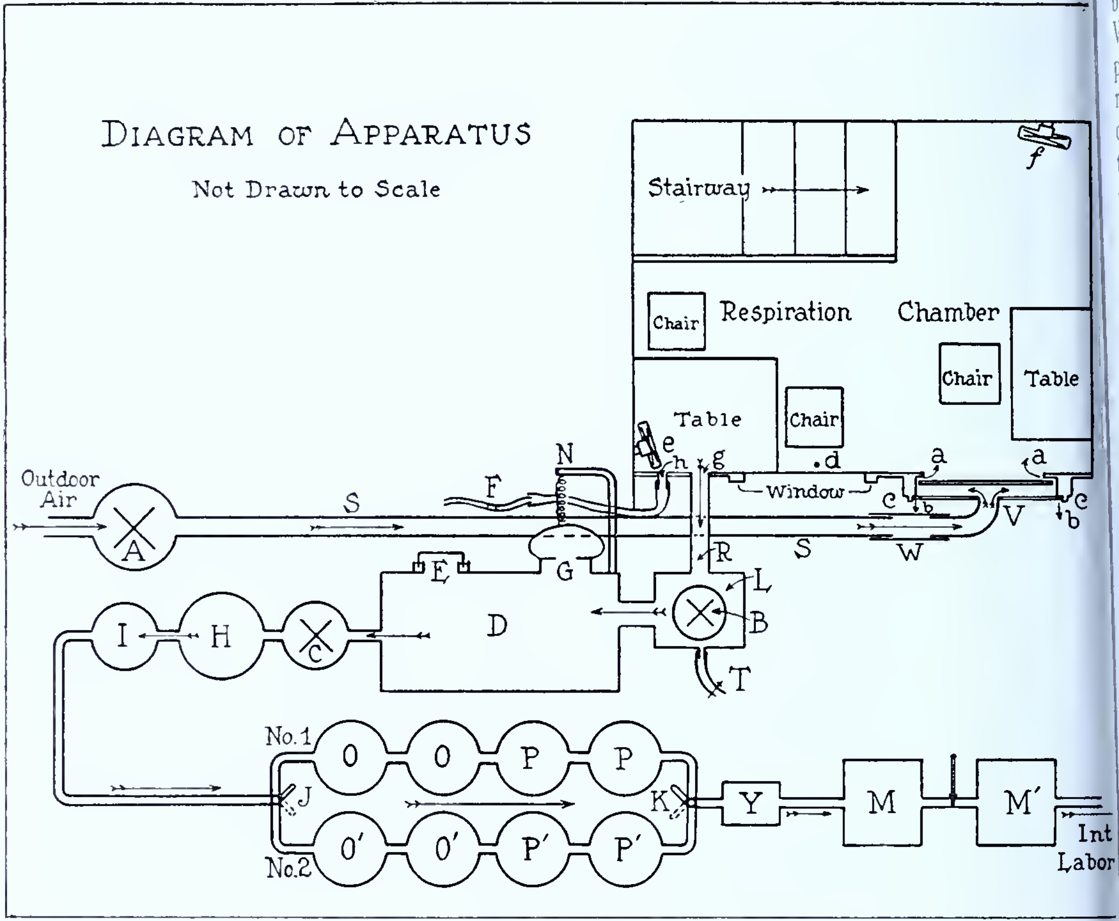
(b) **Description of the Apparatus Used**

The rate of carbon dioxide production by these subjects during quiet play and during stair-climbing was determined by means of a respiration chamber similar to those used by Benedict[12] in Boston and by Benedict and Ritzman[13, 14, 15] in Durham, N. H. The oxygen consumption of the subjects, under standard basal metabolism conditions (lying still awake, 12 to 18 hours after the last food intake, normal body temperature, and comfortable room temperature), and also between three and four in the afternoon while lying down after thirty minutes of rest and while standing quietly, was determined by means of the Benedict and Benedict Student Respiration Apparatus.[16]

Description of the respiration chamber.—The three essentials of a respiration chamber are (1) an air-tight space in which the subjects can perform the activity to be studied, (2) a means of admitting fresh, outdoor air into this space, and (3) a means of determining quantitatively the carbon dioxide produced by the subjects during the test. The size of the chamber should be such that it is large enough to allow ample room for the activity, yet small enough to permit the accumulation of an accurately measurable amount of carbon dioxide within a relatively short time. Fresh air from outside is forced into the chamber by means of a rotary blower, and another blower draws air from the chamber and forces it through a set of absorbers, which remove the carbon dioxide quantitatively. That part of the carbon dioxide produced during the test which remains in the chamber is determined from the difference in carbon dioxide content of the chamber air at the beginning and at the end of the period.

The respiration chamber used in this investigation consists of an air-tight sheet metal shell, 271.2 cm. high, 221.7 cm. long, and 171.6 cm. wide, within a framework of wooden beams to which the metal walls, ceiling, and floor are attached. Number 28 gauge (0.020″) galvanized sheet iron was used throughout. All seams and openings for nails and electric wiring are soldered or cemented to prevent leakage of air either into or out of the chamber. The metal floor is covered with a thin wooden floor which lacks about two centimeters of being as long as the chamber at either end, thus allowing free circulation of air in the spaces under the floor between the cross beams to which the flooring is attached. The floor is varnished; the metal walls and ceiling are painted with a light tan oil paint. In one side of the chamber are a window and a door. (See diagram on page 10.) The window is 76.5 cm. by 91.2 cm. and is 83.6 cm. from the floor. It is of glass, reinforced with wire netting, and is sealed into the metal wall by means of putty.

The door consists of two wooden panels, the inner one 74 cm. by 203 cm., the outer one 79 cm. by 206 cm., fastened together at ten points around the edge by means of thin pieces of wood 5 cm.



by 13 cm., thus leaving a hollow air space the size of the door and 5 cm. deep between the two panels. The panels are painted like the walls and ceiling of the chamber. On the outside of this double door are two handles by means of which it can be easily set in place in the door frame and removed. Next to the edge of the outer surface of the inner panel is pasted a two-centimeter strip of heavy felt. When the door is in place, this felt is pressed tightly against a similar strip of felt on the door frame at *a*. (See diagram on page 10.) The outer panel of the door rests against a metal jamb, *b*, the metal of which is a continuation of the metal wall inside the chamber. Fastened to the door frame on the outside of the chamber at *c* are four clamps, two on either side, which hold the door firmly in place when it is closed.

Ventilation of the chamber.—In the center of the outer panel of the door is a round opening 5 cm. in diameter into which is fastened, by means of a metal collar, a steel pipe, V, of the same diameter. When the chamber is closed, this pipe is connected with another pipe, S, of the same size by means of a twenty-centimeter length of rubber tubing, W. When the chamber is being ventilated, fresh outdoor air is forced by a motor and blower, A (Sirocco, No. 0), through this pipe into the air space between the two door panels, thus increasing the air pressure within this space. Some of this fresh air leaks into the chamber through the felt around the edge of the inner panel at *a*, the remainder passing through the narrow crevice around the outer panel at *b* into the laboratory. The passage of the outdoor air in both directions from this space between the two panels prevents the leakage of any chamber air out into the laboratory and of air from the laboratory into the chamber. Two small electric fans, *e* and *f*, two meters from the floor and in opposite corners of the room, keep the air well mixed. Near the window and about thirty centimeters from the floor is a round opening, *g*, five centimeters in diameter, which is covered with screen of a medium mesh. On the chamber wall there is attached to this opening a metal pipe, R, of the same diameter which leads to an air-tight metal box, L. This box contains a small motor and a rotary blower (Sirocco, No. 00), which draws the air from the chamber and sends it into an air-tight metal compartment, D. The box L is closed by means of a water-sealed cover. The rate of withdrawal of air from the chamber by this blower is regulated by a rheostat. A delicate petroleum manometer, F, which registers the slightest difference in pressure between the chamber and the laboratory, is attached to a small opening, *h*, in the chamber wall by means of a rubber tube. Thus the air pressure within the chamber can be easily kept the same as that in the laboratory. Near the window, at *d*, there hangs a thermometer which can be read from the laboratory. The metal box D has two openings. One is covered with an ordinary bathing cap, G, to the center of which is fastened a spring by means of which it is attached to a point, N, above. The extent of inflation of this cap is an indication of the relative air pressure in the box D. The maintenance of the pressure within this box at atmospheric level is important because fluctuations in it may affect the pressure in the chamber. The other opening, E, is ten centimeters in diameter and is surrounded by a groove filled with water. This is covered during a test with a solid metal cap which fits down into the water seal. During a test the suction pump C draws air from the box D and sends it through two bottles of concentrated sulfuric acid, H and I, to remove the water, then through one of the absorbing trains, number 1 or number 2, depending on the position of the reversible levers J and K. The carbon dioxide is removed from the air by two soda lime absorbers, O, O or O′, O′; any moisture given off by the soda lime is absorbed by two bottles of concentrated sulfuric acid, P, P or P′, P′. The difference in weight of the absorbing train before and after a test is the weight of carbon dioxide in the air which passed through it. The absorbers are weighed on a Sauter balance to within 0.01 gram. This balance has a capacity of 5 kilograms and weighs accurately to within 5 milligrams. The air coming from the last sulfuric acid bottle contains an unweighable trace of acid fumes, which is removed by dry sodium bicarbonate between two layers of cotton in the small metal can Y. From here the air goes through two dry meters, M and M′, and then passes out into the laboratory. The volume of the air passing through these meters is the same as that of the outdoor air which entered the chamber during the test through the crevice around the door, provided the temperature is approximately constant. From this volume is calculated the amount of carbon dioxide in the outdoor air introduced into the chamber during a test by the process of ventilation. The carbon dioxide content of outdoor air has been found by Benedict,[17, 18] and also by other investigators, to be 0.030 per cent, ±0.003 per cent. The carbon dioxide content of New York air was found to be within this range. This value has, therefore, been used throughout this investigation.

Just before and after each test a sample of air is taken from the chamber through a rubber tube attached to the opening *h* in the chamber wall and into a pipette over mercury. These samples are analyzed for carbon dioxide by means of the Carpenter modification of the Haldane gas analysis apparatus.[18, 19, 20] With this apparatus the carbon dioxide content of air can be determined to within 0.004 per cent. Throughout this investigation all samples of air were analyzed until duplicate values within this range were obtained. Once a week samples of outdoor air were analyzed for carbon dioxide content as a check on the gas analysis apparatus. A result between 0.027 and 0.033 per cent was considered proof that the apparatus was in good order.

Testing the chamber.—Before the investigation was begun the apparatus was tested and a sufficient number of tests were made to establish its efficiency. First the absorbing trains alone were tested. This was done by admitting a known weight of gaseous carbon dioxide from a cylinder of the compressed gas into the blower B through the rubber tube T while the whole system was being ventilated. The carbon dioxide was carried directly by the air current through the box D to the absorbing train. The gain in weight of the train indicated the carbon dioxide recovered. The results of these tests (given in Table II, page 13) show that each absorbing train gave an average return of 100 per cent, ±1.1 per cent, of the carbon dioxide passed through it.

The apparatus as a whole was tested by introducing a known weight of the gaseous carbon dioxide into the chamber through the opening *h* in the chamber wall while the entire system was being ventilated. The amount of carbon dioxide recovered indicated the efficiency of the apparatus as a whole. During the period of investigation the chamber was tested on both absorbing trains about once a week. The results of these tests are given in Table III, page 14. The percentage of carbon dioxide recovered ranged from 96.4 to 102.8, averaging 99.7. A typical calculation for a carbon dioxide check test is given in Table IV, page 15.

TABLE II.—RESULTS OBTAINED IN TESTING ABSORBING TRAINS

Date	(a) Carbon dioxide introduced gm.	(b) Increase in weight of train gm.	(c) Carbon dioxide in outdoor air* gm.	(d) Carbon dioxide recovered (b)-(c) gm.	(e) Per cent recovery
Train I—					
1931					
Oct. 19	10.60	10.92	0.20	10.72	101.1
20	13.41	13.72	0.21	13.51	100.7
20	19.98	20.07	0.21	19.86	99.4
20	14.05	14.10	0.20	13.90	98.9
21	23.72	23.91	0.20	23.71	100.0
				Average	100.0
Train II—					
Oct. 19	12.39	12.63	0.19	12.44	100.4
20	10.49	10.59	0.21	10.38	99.0
20	12.33	12.65	0.23	12.42	100.7
20	16.63	16.73	0.21	16.52	99.3
21	16.24	16.45	0.21	16.24	100.0
				Average	99.9

* The outdoor air passing through the apparatus during the test contained 0.030 per cent carbon dioxide. The difference between the meter readings before and after a test is the volume of the outdoor air that passed through the system. At room temperature and the average New York barometric pressure (760 mm.) 100 liters of outdoor air contain 0.055 gram of carbon dioxide. So, the liters of outdoor air ÷ 100 × 0.055 will give the grams of carbon dioxide in the train which were derived from the outdoor air passing through the apparatus during the test.

The Benedict and Benedict Student Respiration Apparatus.[16]—This is a closed circuit type of apparatus for determining heat production indirectly from oxygen consumption. The subject is attached, by means of a rubber mouthpiece, to a closed system containing oxygen-rich air and soda lime. A nose clip insures all breathing being done through the mouth. By means of one-way valves

TABLE III.—CARBON DIOXIDE TESTS OF THE CHAMBER

Date		CO_2 introduced into chamber—gm.	CO_2 recovered in absorbing train—gm.	CO_2 in outdoor air going through chamber—gm*	(b)-(c)—gm.	Residual CO_2 before—%	Residual CO_2 after—%	CO_2 recovered in residual air—gm.†	Total CO_2 recovered (d)+(g)—gm.	Per cent recovery
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
1931										
Dec.	14	60.95	4.59	0.29	4.30	0.052	0.350	56.62	60.92	100.0
	14	53.71	6.86	0.28	6.58	0.350	0.602	47.88	54.46	101.4
1932										
Jan.	27	46.21	4.41	0.34	4.07	0.082	0.303	41.99	46.06	99.7
	27	53.28	7.67	0.34	7.33	0.303	0.542	45.41	52.74	99.0
	29	45.26	3.82	0.29	3.53	0.033	0.252	41.61	45.14	99.7
	29	53.63	6.23	0.30	5.93	0.252	0.511	49.21	55.14	102.8
Feb.	8	46.87	3.42	0.32	3.10	0.030	0.259	43.51	46.61	99.4
	8	47.97	5.61	0.32	5.29	0.259	0.484	42.75	48.04	100.1
	12	49.11	4.42	0.40	4.02	0.065	0.305	45.60	49.62	101.0
	12	35.43	6.60	0.40	6.20	0.305	0.457	28.88	35.08	99.0
	22	42.08	5.59	0.48	5.11	0.034	0.229	37.05	42.16	100.1
	22	35.40	7.22	0.36	6.86	0.229	0.375	27.74	34.60	97.7
	29	64.95	5.60	0.32	5.28	0.037	0.350	59.47	64.75	99.7
	29	48.73	7.97	0.31	7.66	0.350	0.560	39.90	47.56	97.6
Mar.	7	74.87	7.18	0.31	6.87	0.059	0.420	68.59	75.46	100.8
	7	58.80	9.32	0.31	9.01	0.420	0.677	48.83	57.84	98.4
	14	62.19	7.75	0.48	7.27	0.034	0.321	54.53	61.80	99.4
	14	71.05	10.97	0.44	10.53	0.321	0.646	61.75	72.28	101.7
	21	52.74	8.17	0.34	7.83	0.301	0.532	43.89	51.72	98.1
	30	58.24	3.65	0.33	3.32	0.033	0.319	54.34	57.66	99.0
	30	42.98	5.69	0.34	5.35	0.319	0.518	37.81	43.16	100.4
Apr.	4	46.68	2.70	0.32	2.38	0.040	0.269	43.51	45.89	98.3
	4	15.26	3.26	0.31	2.95	0.269	0.333	12.16	15.11	99.0
	11	44.22	2.87	0.32	2.55	0.034	0.250	41.04	43.59	98.6
	11	45.77	5.14	0.34	4.80	0.250	0.469	41.61	46.41	101.4
	18	92.64	5.27	0.34	4.93	0.041	0.485	84.36	89.29	96.4
	18	56.30	8.73	0.34	8.39	0.485	0.736	47.69	56.08	99.6
	25	67.48	4.77	0.32	4.45	0.030	0.363	63.27	67.72	100.4
	25	37.48	7.45	0.32	7.13	0.363	0.525	30.78	37.91	101.2
May	2	61.04	3.94	0.32	3.62	0.029	0.338	58.71	62.33	102.1
	2	43.23	6.42	0.35	6.07	0.338	0.530	36.48	42.55	98.4
	9	40.52	2.24	0.30	1.94	0.031	0.233	38.38	40.32	99.5
	9	35.52	4.50	0.34	4.16	0.233	0.397	31.16	35.32	99.4
									Average	99.7

---

* See footnote, Table II, page 13.

† Each 0.001 per cent increase in residual carbon dioxide means the retention of 0.19 gram carbon dioxide in the chamber (at 760 mm. and 20° C.). This factor is obtained as follows: volume of the chamber × 0.001% × 44/22.4 × 273/293, the volume of the chamber being 10,356 liters. This factor does not change appreciably within the temperature range of 18 to 22 degrees Centigrade and the pressure range of 750 to 770 mm.

TABLE IV.—TYPICAL CALCULATION OF A CARBON DIOXIDE CHECK TEST OF THE CHAMBER

(March 30, 1932, Test I)

Weight of absorbing train—				
At end of period	1,388.94 gm.			
At beginning of period	1,385.29			
Carbon dioxide absorbed by train		3.65 gm.		
Volume of air going through meters (liters)	606.4			
Carbon dioxide in this air*		0.33 gm.		
Carbon dioxide in the absorbing train obtained from the chamber			3.32 gm.	
Residual carbon dioxide in chamber—				
At end of period	0.319%			
At beginning of period	0.033%			
Carbon dioxide introduced into and remaining in the chamber after the test†			54.34 gm.	
Total carbon dioxide recovered				57.66 gm.
Weight of carbon dioxide cylinder—				
Before the test	622.01 gm.			
After the test	563.77			
Amount of carbon dioxide admitted into chamber				58.24 gm.
Difference between carbon dioxide introduced and the amount recovered				00.58 gm.
Per cent recovery				99.0

* See footnote in Table II, page 13.
† See footnote † in Table III, page 14.

and the respiration of the subject, the air circulates in such a way that the person being tested inhales carbon dioxide-free, water-saturated air, all the carbon dioxide produced by the subject being absorbed by the soda lime. Room air, after being saturated with water vapor, is introduced into the system by means of a calibrated pump to replace the oxygen used by the subject. A metal stud in the center of a rubber bathing cap, which forms the top of the can from which the subject obtains the oxygen, makes contact with a point above with each expiration. The total volume of air in the system is kept constant throughout the test by introducing sufficient room air to keep the level of the cap the same at the end of each expiration. The volume of room air added to the system during the test equals the volume of oxygen used by the subject during the time of the test.

(c) **Experimental Procedure**

Activities studied.—In selecting the activities to be studied, types of exercise were chosen which could be duplicated from day to day, which were as nearly as possible representative of normal activities of children, and which would be carried out by the children in a spontaneous manner.

The first kind of activity studied—quiet, individual play while seated at a table—is entirely natural to children of this age. It required no instructions after the first few tests and was quite spontaneous on the part of the subjects. Their activity during this period was controlled, to a great extent, by the type of play offered and by their interest in what they were doing. They liked such occupations as solving picture puzzles, coloring and drawing, cutting paper dolls, and clay modeling, and always continued the selected form of activity throughout the period of quiet play (preceded by a preliminary period of five minutes) without showing any signs of ennui. New games were added from time to time to maintain interest. Fortunately it was found possible to make the test periods long enough to allow of the production of sufficient carbon dioxide to enable its determination to within the desired degree of accuracy—namely, 5 per cent—and yet short enough to prevent loss of interest on the part of the children during the period. Preliminary tests indicated that the optimum length of time for this activity in the chamber was twenty minutes. Their activity during repetitions of the test from day to day seemed to the observer to be very much the same, though the carbon dioxide produced per child per hour varied from 21.40 to 31.43 grams.

The second kind of activity studied was more stereotyped. In order to be readily duplicated it had to be carefully controlled and was, consequently, less spontaneous, but it involved no movements that are not made by children in the course of a day's work and play. It consisted of walking up and down a little staircase of four steps. One subject at a time and each in her turn climbed the staircase, always keeping step to a metronome, which was set at 116 beats per minute. There was thus always one girl on the stairway and never more than one at a time. Each girl, therefore, spent one-third of her time during this activity period on the stairway. This stair-climbing consisted of the following movements: two preliminary steps before ascending the stairs, four steps in ascending, two steps in turning at the top, and four steps in descending. The whole process required the time of twelve beats of the metronome, or about six seconds. Each subject spent the intervening twelve seconds between her ascents walking around to her place in line and standing awaiting her turn. The carbon dioxide production per child per hour during this activity ranged from 46.83 grams to 62.13 grams. The variation is not surprising to one who observed the subjects during several of these stair-climbing periods. The activity indulged in during the stair-climbing varied all the way from approximately the minimum required to perform the assigned task to an amount obviously greatly in excess of this on days when they felt extremely vivacious, although it is very doubtful whether the work was ever, throughout any whole period, done with the least possible expenditure of muscular effort. However, the range in carbon dioxide production in this series of duplicated experiments is not greater than other investigators have found with adult subjects and more rigidly controlled activity.* It was not possible to control the activity more completely, since the only means of communicating with the children during a test was by motioning to them through the window. The construction of the respiration chamber offered no facilities for speaking to the children during a test. This spontaneous variation, however, in the manner and cost of performing a given task repeatedly is probably not greater than the difference, from day to day, in the amount of energy a child expends in performing the daily routine tasks of dressing, eating, walking, and so forth. During the period of stair-climbing the whole body, more or less, was moderately active most of the time, but the exercise was not strenuous enough to make the children perspire, and they were never out of breath or tired after a test. In extent of muscular activity it was perhaps comparable to continuous, moderately active, outdoor play. The optimum length of the test period for this activity was found to be fifteen minutes.

A typical test in the chamber.—There were three subjects in the chamber each period, all possible combinations of three out of the six subjects being used at least once. The subjects came to the laboratory at about 2.30 P.M., directly from the public school. Each afternoon's test consisted of two periods in the respiration chamber—a twenty-minute period of quiet play, immediately followed by a fifteen-minute period of stair-climbing. All these afternoon tests were exact duplicates, so far as procedure is concerned. After receiving the necessary instructions the children selected their favorite pastime for the period of quiet play, entered the chamber, and seated themselves at the tables. After they were nicely started in their various activities, the door of the chamber was put in place and ventilation started, the two electric fans in the chamber having been turned on before the children entered. During a five-minute preliminary period of ventilation the air was allowed to escape from the metal box D by removing the solid cap from the opening E. Meter readings, chamber temperature, and barometric pressure were recorded and levers J and K turned to train number one. At the close of the preliminary period opening E was closed and a sample of air taken from the chamber through opening *h* into a pipette over mercury. Then motor C was turned on, drawing the air from the metal box D and forcing it through the absorbing train. Two stop-watches were started just as motor C was turned on. By means of the rheostat on motor B and the delicate manometer F, the rate of ventilation by the motors was so controlled as to keep the air within the chamber at the same pressure as that in the laboratory. The children could be watched through the window. After twenty minutes motor C was turned off, the rate of motor B was greatly reduced, a sample of air was taken from the chamber through the opening at *h*, and the subjects in the chamber were given the signal to begin the stair-climbing. Levers J and K were turned so that the air from the chamber would now pass through absorbing train number two, and meter readings, chamber temperature, and time were recorded. By this time (about two minutes) one of the subjects, the captain, had turned on the metronome (previously wound and set) and the stair-climbing had been nicely started. Then motor C was turned on again, the stop-watches started at the same time, and the speed of motor B adjusted. After a fifteen-minute period of stair-climbing motor C was turned off, the temperature of the chamber and the time were recorded, a sample of chamber air taken, and the door removed. After the children left the meters were read, the absorbers weighed, and the air samples analyzed for carbon dioxide. The results obtained in thirty-six such determinations are to be found in Table V, page 21. A graphic representation of these results is shown on page 20.

---

* See page 24, "Discussion of Results."

Determination of the resting metabolism.—By means of the Benedict and Benedict Student Respiration Apparatus[16] the oxygen consumption of each subject was determined at the same time of day —between 3 and 4 P.M.—under two conditions: while lying down after 30 minutes of rest, and while standing. The rate of oxygen consumption of the subjects was also determined under standard basal energy metabolism conditions in the morning before the subjects arose. In determining the basal heat production, tests were made on each subject on at least two mornings and not less than two tests each morning. The tests on each subject were repeated until at least two mornings gave figures which checked within 5 per cent of the lowest figure obtained. The lowest figure obtained on a subject and all those values within 5 per cent of it were averaged to obtain the basal rate of oxygen consumption of that subject. The basal energy metabolism of each subject, calculated from the basal rate of oxygen consumption thus obtained, may be found in Table VI, page 22.

The rate of oxygen consumption in the middle of the afternoon, even after thirty minutes of rest, was found, as was to be expected from results already reported in the literature, to be more variable than it was in the morning before rising. Four determinations were made on each subject, covering two or more days. All individual tests and the average for each subject are to be found in Table VII, page 23.

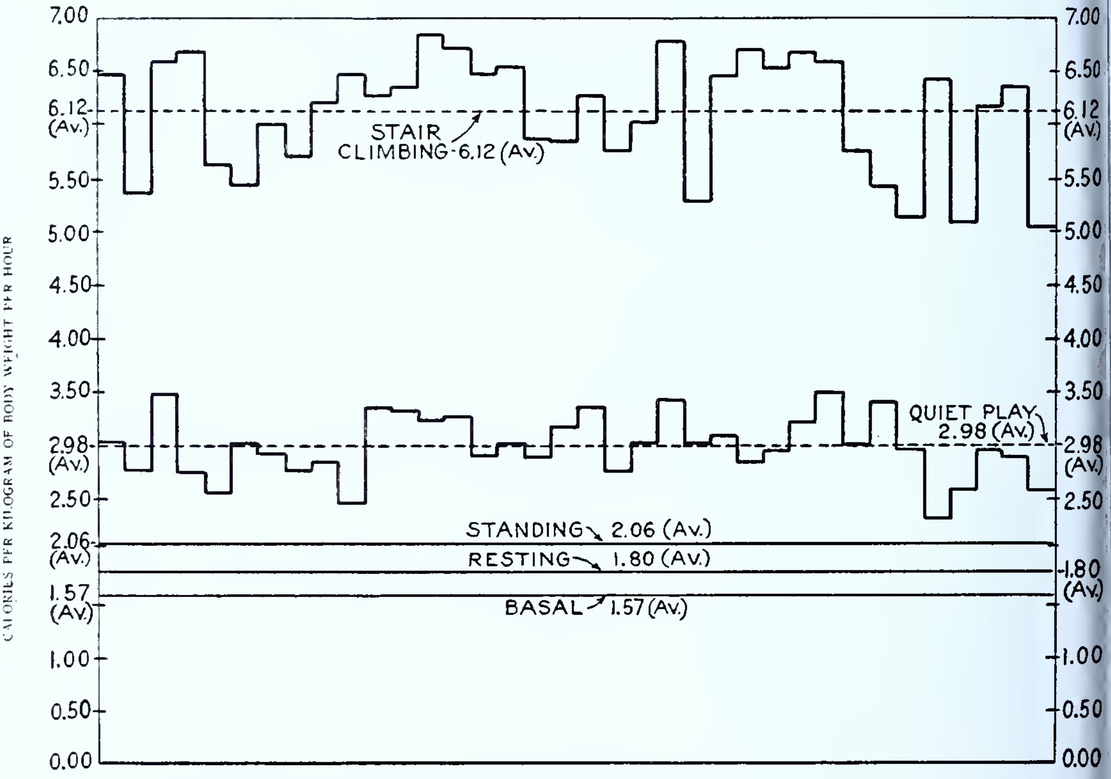
The rate of oxygen consumption while standing in the afternoon was found to be still more variable (as much as 24 per cent in one subject). Because of the discomfort of standing ten minutes, only three determinations (on three different days) were made on each subject in this position. During these tests the subject stood between two chairs, the backs of which were placed close to her on either side, so that she could put one or both hands on a chair back to support herself if she became tired. Whenever it was noticed that the subject became tired during a test the time was shortened. The shortest period was six minutes; the others ranged from seven to ten minutes. The values obtained in individual tests and the average for each subject are to be found in Table VII, page 23.

COMPUTATION OF RESULTS

(a) Calculation of Energy Expenditure During Exercise from the Carbon Dioxide Production

Atwater and Rosa,[21] with the chamber calorimeter, established the fact that the gaseous exchange is a reliable measure of the heat production. Armsby,[22] from experiments with cattle, concluded that the ratio of carbon dioxide: heat is constant enough, under certain constant conditions in the animal body, to permit the determination of heat production from carbon dioxide excretion, with a "good degree of accuracy." In these experiments the carbon dioxide output during exercise was determined and from this the energy cost of the activity was calculated. In calculating calories from carbon dioxide production, a respiratory quotient of 0.82 was assumed. The investigations were always carried out from four to five hours after taking food—namely, lunch, at 11 A.M. Under such conditions it has been shown by several investigators that the respiratory quotient is very nearly that found under standard conditions, namely, 0.82. Bauer and Blunt,[23] in studying the effects of food on the energy metabolism of children, found, in seven children from 10 to 13 years of age, that the effect of a light breakfast had so nearly disappeared in four hours that it no longer influenced the energy metabolism. Marsh,[24] in studying the character of energy metabolism during work, found a fifteen-year-old boy to have an average respiratory quotient of 0.85 during moderate activity three and one-half to four and one-half hours after lunch, with a range of 0.78 to 0.94. Levine and Wilson[25] determined the respiratory quotients of four children five to six and one-fourth hours after eating and found all values to be near the average of 0.82, with a range of 0.78 to 0.85. In a second series of similar experiments[26] they found the average respiratory quotient to be 0.87, with a range of 0.83 to 0.95. Speck[5] reported a respiratory quotient of 0.855 in his ten-year-old girl five hours after breakfast. The average of all these determinations is near 0.85, and the total range covered is 0.78 to 0.95.

The possible error due to the assumption of a wrong respiratory quotient is not great as compared with the variation in carbon



GRAPHIC REPRESENTATION OF THE AVERAGE ENERGY EXPENDITURE AT THE FIVE DIFFERENT LEVELS OF ACTIVITY. THE FLUCTUATION OF THE INDIVIDUAL RESULTS AROUND THE AVERAGE COST OF QUIET PLAY AND OF STAIR-CLIMBING IS CLEARLY SEEN.

TABLE V.—CARBON DIOXIDE PRODUCTION AND EQUIVALENT CALORIES DURING QUIET PLAY AND STAIR-CLIMBING

Date	Subjects	Total wt. of 3 subjects kg.	Total CO_2 produced—gm.		CO_2 per child per hr.—gm.		CO_2 per kg. per hr.—gm.		Calories per kg. per hr.*	
			Quiet play 20 min.	Stair-climbing 15 min.	Quiet play	Stair-climbing	Quiet play	Stair-climbing	Quiet play	Stair-climbing
1931										
Dec. 15	2, 4, 5	80.9	27.23	43.63	27.23	58.17	1.01	2.16	3.02	6.47
17	2, 4, 5	80.9	25.13	36.31	25.13	48.41	0.93	1.79	2.78	5.36
1932										
Feb. 3	1, 3, 6	77.8	30.18	42.78	30.18	57.04	1.16	2.20	3.47	6.59
4	1, 2, 6	81.7	25.29	45.61	25.29	60.81	0.93	2.23	2.79	6.68
9	1, 2, 6	81.7	23.80	38.29	23.80	51.05	0.87	1.88	2.61	5.63
10	3, 4, 5	80.5	27.47	43.20	27.47	57.60	1.02	2.15	3.05	6.44
11	2, 4, 5	84.4	27.23	42.18	27.23	56.24	0.97	2.00	2.91	5.99
16	1, 3, 6	77.8	23.63	37.15	23.63	49.53	0.91	1.91	2.73	5.72
17	3, 5, 6	78.0	24.76	40.40	24.76	53.87	0.95	2.07	2.84	6.20
18	1, 2, 4	84.2	22.51	45.54	22.51	60.72	0.80	2.16	2.40	6.47
23	1, 4, 5	83.1	30.81	43.37	30.81	57.83	1.11	2.09	3.32	6.26
24	1, 2, 3	82.1	30.05	43.56	30.05	58.08	1.10	2.12	3.29	6.35
25	2, 5, 6	81.9	29.45	46.60	29.45	62.13	1.08	2.28	3.23	6.83
Mar. 1	1, 3, 4	80.3	29.24	45.03	29.24	60.04	1.09	2.24	3.26	6.71
2	2, 3, 6	79.1	25.18	42.77	25.18	57.03	0.95	2.16	2.88	6.47
8	4, 5, 6	80.1	26.95	43.73	26.95	58.31	1.01	2.18	3.02	6.53
9	2, 3, 5	82.3	26.37	40.33	26.37	53.77	0.96	1.96	2.88	5.87
10	1, 4, 6	79.9	28.26	38.90	28.26	51.87	1.06	1.95	3.17	5.84
15	2, 4, 5	84.4	31.43	44.10	31.43	58.80	1.12	2.09	3.35	6.26
16	3, 4, 6	77.3	23.82	37.21	23.82	49.61	0.92	1.92	2.76	5.75
17	1, 2, 5	84.9	28.62	42.61	28.62	56.81	1.01	2.01	3.02	6.02
22	1, 3, 6	77.8	29.29	43.97	29.29	58.63	1.13	2.26	3.38	6.77
23	1, 4, 5	83.1	28.08	36.63	28.08	48.84	1.01	1.76	3.02	5.27
29	2, 5, 6	81.9	28.04	43.93	28.04	58.57	1.03	2.15	3.08	6.44
Apr. 12	1, 4, 6	79.9	25.04	44.56	25.04	59.41	0.94	2.23	2.82	6.68
13	1, 3, 5	81.0	26.45	43.90	26.45	58.53	0.98	2.17	2.93	6.50
14	4, 5, 6	80.1	28.55	44.54	28.55	59.39	1.07	2.22	3.20	6.65
19	1, 3, 6	77.8	30.25	42.59	30.25	56.79	1.16	2.19	3.47	6.56
20	1, 3, 4	80.3	27.16	38.47	27.16	51.29	1.01	1.92	3.02	5.75
21	3, 5, 6	78.0	29.49	35.12	29.49	46.83	1.13	1.80	3.38	5.39
26	1, 2, 4	88.1	28.72	37.64	28.72	50.19	0.98	1.71	2.93	5.12
27	2, 3, 4	84.2	21.40	45.02	21.40	60.03	0.76	2.14	2.28	6.41
28	1, 3, 5	84.3	24.10	35.54	24.10	47.39	0.86	1.69	2.58	5.06
May 3	2, 4, 6	83.9	27.54	43.10	27.54	57.47	0.98	2.05	2.93	6.14
4	1, 2, 3	86.2	27.50	45.37	27.50	60.49	0.96	2.11	2.88	6.32
5	1, 5, 6	84.0	24.03	35.31	24.03	47.08	0.86	1.68	2.58	5.03
Average		81.5	27.03	41.64	27.03	55.52	1.00	2.05	2.98	6.12
Range			21.40 to 31.43	35.12 to 46.60	21.40 to 31.43	46.83 to 62.13	0.76 to 1.16	1.68 to 2.28	2.28 to 3.47	5.03 to 6.83

---

* The calorific value of 1 gram of carbon dioxide is 2.994 (calculated from the calories per liter of carbon dioxide given by Zuntz and Schumburg[27] for the respiratory quotient of 0.82).

dioxide production in repeated performances of the same activity. At a respiratory quotient of 0.82 the calorific value of one liter of carbon dioxide is 5.884;[27] at 0.78 it is 6.123; at 0.95 it is 5.247. If the respiratory quotient be anywhere between 0.78 and 0.95, the maximum error due to assuming 0.82 as the respiratory quotient is not greater than —4.1 per cent or +10.8 per cent. The variation in grams of carbon dioxide produced per kilogram of body weight per hour during quiet play was about twice as great as this. If the average respiratory quotient were 0.85 instead of 0.82, as was assumed in the calculation, the average error would be as low as —2.8 per cent, since the calorific value of one liter of carbon dioxide is 5.721 at a respiratory quotient of 0.85.

In the light of the results obtained by the investigators cited above, and of the fact that all determinations in the present study were carried out from four to five hours after the last food intake, assumption of a respiratory quotient of 0.82 in these subjects seemed justified and was, therefore, used in calculating calories of energy expended from carbon dioxide produced. The calorific value of one gram of carbon dioxide at this respiratory quotient is 2.994.

Table V, page 21, gives the carbon dioxide production and the energy expenditure calculated therefrom during thirty-six periods in the respiration chamber, in each of which the two different kinds of activity were studied. The average results, expressed in terms of Calories per kilogram of body weight, are as follows:

Activity	Mean	Range	Standard deviation	Coefficient of variation	Probable error of the mean
Quiet play	2.98	2.28-3.47	±0.29	9.73	±0.03
Stair-climbing	6.12	5.03-6.83	±0.52	8.50	±0.06

(b) Calculation of Energy Expenditure During Rest from the Oxygen Consumption

Table VI, below, gives the basal metabolism of ths subjects calculated from oxygen consumption. At a respiratory quotient of 0.82 the calorific value of one liter of oxygen is 4.825.[27]

TABLE VI.—BASAL METABOLISM OF THE SUBJECTS

Subject	Age yr.-mo.	Oxygen consumption cc. per min.	Cal. per 24 hr.	Cal. per hr.	Cal. per sq. m. per hr.	Cal. per kg. per hr.	Cal. per cm. of ht. per 24 hrs.
1	9-10	154.4	1,073	44.7	44.7	1.61	8.29
2	10- 1	139.2	967	40.3	38.0	1.38	7.16
3	9- 4	135.4	941	39.2	43.1	1.56	7.87
4	9- 5	147.6	1,026	42.7	43.6	1.57	8.12
5	9- 8	159.5	1,109	46.2	47.1	1.65	8.86
6	10- 2	140.5	976	40.7	43.8	1.64	7.83
Average		146.1	1,015	42.3	43.4	1.57	8.02

Table VII, below, gives the oxygen consumption and the heat production calculated therefrom, between three and four o'clock in the afternoon while lying down after thirty minutes of rest and while standing.

TABLE VII.—OXYGEN CONSUMPTION AND ENERGY EXPENDITURE WHILE LYING DOWN AND WHILE STANDING BETWEEN 3 AND 4 P.M.

Subject No.	Oxygen consumption—cc. per minute: Individual determinations 1	2	3	4	Average	Energy expenditure—Calories: per kg. per hr.	total per hr.	per sq. m. per hr.	per cm. ht. per day
				Lying down after 30 minutes' rest					
1	178.7	189.3	192.6	194.8	188.9	1.84	54.7	52.6	9.92
2	174.0	176.4	175.3	172.6	174.6	1.65	50.6	46.4	8.79
3	162.8	162.0	164.0	159.1	162.0	1.82	46.9	49.9	9.20
4	171.6	163.3	174.0	177.4	171.6	1.79	49.7	49.7	9.23
5	177.0	181.0	174.7	171.2	176.0	1.77	51.0	50.0	9.47
6	167.8	160.7	176.7	178.4	170.9	1.94	49.5	50.7	9.24
Average					174.0	1.80	50.4	49.9	9.31
				Standing					
1	228.5	224.2	191.8		214.8	2.09	62.2	59.8	11.28
2	180.6	200.7	201.9		194.4	1.83	56.3	51.6	9.79
3	162.4	174.2	201.5		179.4	2.01	51.9	55.3	10.18
4	206.4	227.1	186.5		206.7	2.16	59.8	59.8	11.12
5	187.7	200.6	214.5		200.9	2.02	58.2	57.0	10.80
6	199.6	200.9	185.3		195.3	2.22	56.6	58.3	10.62
Average					198.6	2.06	57.5	57.0	10.63

TABLE VIII.—HEAT PRODUCTION UNDER FIVE DIFFERENT CONDITIONS AND A COMPARISON OF THE FIGURES WITH ONE ANOTHER

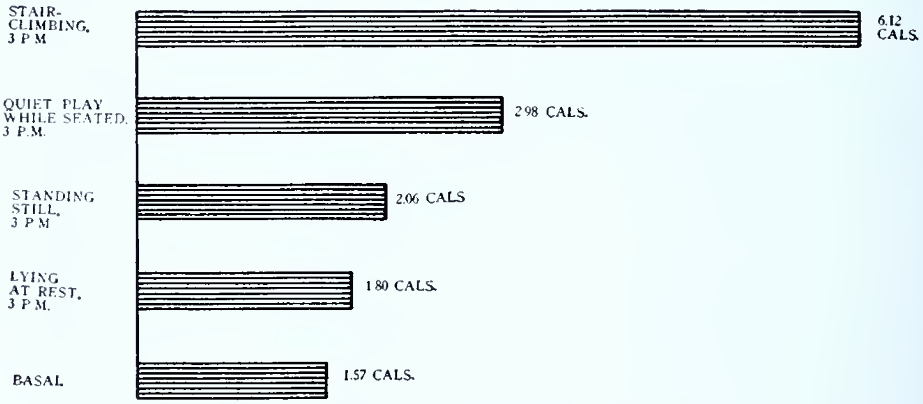
	(a)	(b)			(c)				
Subject No.	Cal./kg./hr. (basal)	Cal./kg./hr., lying down, 3 p.m.	Increase of (b) over (a)		Cal./kg./hr., standing, 3 p.m.	Increase of (c) over (a)		Increase of (c) over (b)	
			Cal.	Per cent		Cal.	Per cent	Cal.	Per cent
1	1.61	1.84	0.23	14	2.09	0.48	30	0.25	14
2	1.38	1.65	0.27	20	1.83	0.45	33	0.18	11
3	1.56	1.82	0.26	17	2.01	0.45	29	0.19	11
4	1.57	1.79	0.22	14	2.16	0.59	38	0.37	21
5	1.65	1.77	0.12	7	2.02	0.37	22	0.25	14
6	1.64	1.94	0.30	18	2.22	0.58	35	0.28	14
Average	1.57	1.80	0.23	15	2.06	0.49	31	0.26	14

TABLE VIII—*Continued*

	(d)					(e)						
Subject No.	Cal./kg./hr., quiet play, 3 p.m.	Increase of (d) over (a)		Increase of (d) over (b)		Cal./kg./hr., stair-climbing, 3 p.m.	Increase of (e) over (a)		Increase of (e) over (b)		Increase of (e) over (c)	
		Cal.	Per cent	Cal.	Per cent		Cal.	Per cent	Cal.	Per cent	Cal.	Per cent
1	2.98	1.37	85	1.14	62	6.12	4.51	280	4.28	233	4.03	193
2	2.98	1.60	116	1.33	81	6.12	4.74	343	4.47	271	4.29	234
3	2.98	1.42	91	1.16	64	6.12	4.56	292	4.30	236	4.11	204
4	2.98	1.41	90	1.19	67	6.12	4.55	290	4.33	242	3.96	183
5	2.98	1.33	81	1.21	68	6.12	4.47	271	4.35	246	4.10	203
6	2.98	1.34	82	1.04	54	6.12	4.48	273	4.18	216	3.90	176
Average	2.98	1.41	90	1.18	66	6.12	4.55	290	4.32	240	4.06	197

DISCUSSION OF RESULTS

In Table VIII, page 23, are to be found the heat production under five different conditions and a comparison of these figures with one another. These figures and increases are shown graphically as follows:



GRAPHIC REPRESENTATION OF ENERGY EXPENDITURE IN CALORIES PER KILOGRAM OF BODY WEIGHT PER HOUR UNDER FIVE DIFFERENT CONDITIONS.

The average total heat production during quiet play was found to be 2.98 Calories per kilogram of body weight per hour. This is an increase of 1.41 Calories, or 90 per cent, over the average basal heat production, and an increase of 1.18 Calories, or 66 per cent, over heat production during complete rest in the afternoon. Likewise, the average total heat production during the stair-climbing period (in which one-third of each subject's time was spent in actual exercise on the stairway, the other two-thirds being spent in walking to and standing in her place in line) was found to be 6.12 Calories per kilogram of body weight per hour, which is an increase of 4.55 Calories, or 290 per cent, over the average basal heat production, an increase of 4.32 Calories, or 240 per cent, over the average heat production during rest in the afternoon, and an increase of 4.06 Calories, or 197 per cent, over the average heat production while standing still.

There are very few figures in the literature with which to compare these results. Speck[5] found that a ten-year-old girl expended about two Calories per kilogram of body weight per hour while sitting still reading five hours after breakfast. The subjects of the present study expended an average of 2.98 Calories per kilogram of body weight per hour while seated at tables engaged in quiet individual play. This is 50 per cent more than the former. Sondén and Tigerstedt's[6] nine-year-old girls produced 22.6 grams of carbon dioxide each, or 0.85 gram per kilogram of body weight, per hour while sitting still in the respiration chamber. The subjects of this experiment produced an average of 27.03 grams of carbon dioxide each, or 1.00 gram per kilogram of body weight, per hour during their period of quiet play. This is about 18 per cent more than Sondén and Tigerstedt's subjects produced while slightly less active.

There are a few figures for adult women with which it might be of interest to compare the figures obtained on these children. It seemed to the observer that the degree of activity of the subjects of this investigation during the period of quiet play might approximate that of women sewing by hand. Langworthy and Barott[28] found the total energy expenditure of a woman, while sitting engaged in hand sewing, to be 1.11 Calories per kilogram of body weight per hour, or an increase of 0.09 Calorie per kilogram per hour, or 9 per cent, over her resting metabolism. In these nine-year-old girls the energy expenditure during quiet play was 2.98 Calories per kilogram of body weight per hour. This is an increase of 1.18 Calories per kilogram per hour, or 66 per cent, over their resting metabolism at 3 P.M.

Benedict and Johnson[29] found the average total energy expenditure of fifteen young women, engaged in hand sewing, to be 1.27 Calories per kilogram of body weight per hour, as compared with 2.98 Calories per kilogram per hour in these subjects during quiet play. This was 0.26 Calorie per kilogram per hour, or 26 per cent, over their basal heat production. The average increase in metabolism over the basal level produced by quiet play in the subjects of this research was 1.41 Calories per kilogram per hour, or 90 per cent.

Benedict and Johnson[29] found the energy expenditure of young women standing still to be 1.22 Calories per kilogram of body weight per hour. The average cost of standing in these nine-year-old girls was 2.06 Calories per kilogram per hour, or 69 per cent greater than that of the women in Benedict's study.

The variation in grams of carbon dioxide produced per child per hour in these experiments was from 21.40 to 31.43 during quiet play and from 46.83 to 62.13 during stair-climbing. This is not a greater variation than other experimenters have found in repeated controlled experiments in energy metabolism. Sondén and Tigerstedt[6] found the carbon dioxide production of one adult subject, while sitting still, to vary from 24 to 43 grams per hour, of another, from 19 to 32. Sondén and Tigerstedt's six nine-year-old girls produced from 59 to 76 grams carbon dioxide in four one-half-hour experiments while sitting still in the respiration chamber. In the same laboratory an adult subject during horizontal walking, in three experiments, produced, respectively, 49, 56, and 64 grams of carbon dioxide per hour. In still another investigation these experimenters found that the increase in carbon dioxide production per hour in various adult male subjects, over that during rest, due to ladder-climbing, varied from 50 to 104 grams.

Table IX, below, gives a comparison of the basal energy metabolism of these subjects with the Benedict-height and the Dreyer standards, the only standards thus far established for girls of this age. For girls from six days to twelve years of age Benedict[30] says the most accurate prediction of basal metabolism is made on the basis of total height, while for girls from twelve to twenty years of age he recommends the prediction be made on the basis of the relation-

TABLE IX.—COMPARISON OF BASAL METABOLISM OF THE SUBJECTS WITH STANDARDS

		Calories per 24 hours			Deviation from Standards	
			Standards			
Subject No.	Age yr.-mo.	Actual	Benedict-Height	Dreyer	Benedict-Height %	Dreyer %
1	9-10	1,073	961	1,088	+11.7	— 1.4
2	10- 1	967	1,017	1,114	— 4.9	—13.2
3	9- 4	941	862	1,052	+ 9.2	—10.5
4	9- 5	1,026	928	1,094	+10.6	— 6.2
5	9- 8	1,109	917	1,092	+20.9	+ 1.6
6	10- 2	976	912	1,028	+ 7.0	— 5.1
Average		1,015			+ 9.1	— 5.8

ship between heat production per kilogram of body weight and age. The basal energy metabolism of these subjects differs from the Benedict-height standards for girls of this age by an average for the group of +9.1 per cent, with a range of —4.9 to +20.9 per cent. Dreyer's[31] formula for the prediction of basal energy metabolism of women from weight and age is applicable, according to Dreyer, to all females above the age of five years. The deviation of these subjects from the Dreyer standards for their age ranged from —13.2 to +1.6 per cent, with an average deviation for the group of —5.8 per cent.

The deviations of these subjects from the Benedict standards are similar to those found by other investigators for normal subjects of the same age and sex, as may be seen from the following tabulation:

Investigator	Age range years	No. of subjects	Deviation from Benedict standards Average—%	Range—%
Blunt et al.[32]	9-10	21	+11	+1 to +29
Klugh[33]	6-12	26	+16	—4 to +39
Wang et al.[34]	4-11	9	+10.3	—3.2 to +31.8
This study	9-10	6	+ 9.1	—4.9 to +20.9

Schadow,[35] Kestner and Knipping,[36] and Rosenblüth,[37] in Europe, have also reported finding the Benedict standards somewhat too low, but do not give figures that admit of tabulation. These comparisons seem to indicate that, on the whole, the Benedict standards may well be as much as 10 to 15 per cent too low for girls of this age.

In no other study of the basal energy metabolism of girls of this age have the results been compared with the values predicted by the Dreyer formula. On the basis of these six cases, if one may generalize at all from only six cases, it seems to be true that the Dreyer standards for girls of this age may be as much as 5 per cent too high.

That these girls as a group show an average deviation of +9.1 per cent from one standard and —5.8 per cent from another is evidence of how far from satisfactory are the present standards for normal basal metabolism for girls of this age.

SUMMARY

A large respiration chamber of the open-circuit type has been described. Recovery of carbon dioxide introduced into the chamber was found to range from 96.4 to 102.8 per cent, with an average of 99.7 per cent.

The results of thirty-six periods of investigation of the cost of each of two different kinds of activity on the part of six nine-year-old girls in this respiration chamber are as follows:

Activity	CO_2 per child per hour		CO_2 per kg. per hour		Calories per kg. per hour		Probable error of the average calories
	Average gm.	range gm.	Average gm.	range gm.	Average	range	
Quiet play while seated	27.03	21.40 to 31.43	1.00	0.76 to 1.16	2.98	2.28 to 3.47	±0.03
Stair-climbing...	55.52	46.83 to 62.13	2.05	1.68 to 2.28	6.12	5.03 to 6.83	±0.06

The energy expenditure in Calories per kilogram of body weight per hour of these subjects between three and four o'clock in the afternoon, while lying down after thirty minutes of rest, and while standing, was found to be as follows:

	Calories per kg.of body wt. per hour	
	Average	Range
Lying down	1.80	1.65-1.94
Standing	2.06	1.83-2.22

A comparison of the average energy expenditure during the different activities follows:

	Increase over basal metabolism		Increase over resting at 3 p.m.		Increase over standing at 3 p.m.	
	Cal. per kg. per hr.	Per cent	Cal. per kg. per hr.	Per cent	Cal. per kg. per hr.	Per cent
Quiet play	1.41	90	1.18	66	0.92	45
Stair-climbing	4.55	290	4.32	240	4.06	197
Standing still	0.49	31	0.26	14		
Resting at 3 P.M...	0.23	15				

The basal metabolism of these six subjects was found to be as follows:

	Average	Range
Total calories per 24 hours	1,015	941-1,109
Calories per square meter of body surface per hour....	43.4	38.0 -47.1
Calories per kilogram of body weight per hour.......	1.57	1.38- 1.65
Calories per centimeter of height per day............	8.02	7.16- 8.86

These results deviate from the Benedict-height standards for girls of this age by amounts ranging from —4.9 to +20.9 per cent, with an average deviation of +9.1 per cent. Their variation from the Dreyer standards is from —13.2 to +1.6 per cent, with an average deviation of —5.8 per cent. These deviations from the standards at present available for girls of this age point to the need for further investigation of the basal energy metabolism of healthy young girls, for the purpose of establishing more satisfactory standards.

BIBLIOGRAPHY

[1] Lavoisier and Séguin: Premier mémoire sur la respiration. Mémoires de l'académie des sciences, année 1789, page 185. Cited by Sondén, K., and Tigerstedt, R., Skand. Archiv f. Physiol., Vol. 6, 165 (1895).

[2] Smith, E.: Philosophical Transactions, Vol. 149, 709-711 (1859). Cited by Sondén and Tigerstedt, Archiv f. Physiol., Vol. 6, 165 (1895).

[3] Pettenkofer, M. V., and Voit, C.: Untersuchungen über den Stoffverbrauch des normalen Menschen. Zeit. f. Biol., Vol. 2, 459-573 (1866).

[4] Forster, J.: Ueber die Kohlensäureausscheidung bei Kindern. Amtlicher Bericht Deutscher Naturforscher und Aerzte, der 50. Versammlung, September, 1877, 355.

[5] Speck: Physiologie des menschlichen Athmens, Leipsic, page IV, 1892. Cited by Benedict and Talbot in Metabolism and Growth from Birth to Puberty. Carnegie Inst. Washington, Pub. No. 302, page 8, 1921.

[6] Sondén, K., and Tigerstedt, R.: Untersuchungen über die Respiration und den Gesammtstoffwechsel des Menschen. Skand. Archiv f. Physiol., Vol. 6, 1-224 (1895).

[7] Bedale, E. M.: Energy Expenditure and Food Requirements of Children at School. Proc. Roy. Soc. London, Vol. 94, 368-404 (1923).

[8] Helmreich, E.: Die Besonderheit des Kindlichen Kraftwechsels. Klin. Wochens., Vol. 4, 540-542 (1925).

[9] McClintock, J. T., and Paisley, S.: Cost of Work in Relation to Basal Metabolism. Proc. Soc. Exp. Biol. Med., Vol. 30, 162-163 (1932).

[10] Baldwin, B. T., and Wood, F. D.: Weight-Height-Age Tables. American Child Health Association, New York, 1923.

[11] Carpenter, T. M.: Tables, Factors, and Formulas for Computing Respiratory Exchange and Biological Transformations of Energy, 2nd edition. Carnegie Inst. Washington, Pub. No. 303A, 1924.

[12] Benedict, F. G., Miles, W. R., Roth, P., and Smith, H. M.: Human Vitality and Efficiency Under Prolonged Restricted Diet. Carnegie Inst. Washington, Pub. No. 280, pages 95-119, 1919.

[13] Benedict, F. G., Collins, W. E., Hendry, M. F., and Johnson, A.: A Respiration Chamber for Large Domestic Animals. New Hampshire Station Technical Bulletin No. 16, 1920.

[14] Benedict, F. G., and Ritzman, E. G.: Undernutrition in Steers. Carnegie Inst. Washington, Pub. No. 324, pages 46-74, 1923.

[15] Ritzman, E. G., and Benedict, F. G.: Simplified Technique and Apparatus for Measuring Energy Requirements of Cattle. Agricultural Experiment Station, University of New Hampshire, Durham, N. H., Bulletin No. 240, 1929.

[16] Benedict, F. G., and Benedict, C. G.: A Student Form of Respiration Apparatus. The Boston Med. Surg. J., Vol. 188, 567-577 (1923).

[17] Benedict, F. G.: The Composition of the Atmosphere with Special Reference to Its Oxygen Content. Carnegie Inst. Washington, Pub. No. 166, 1912.

[18] Carpenter, T. M.: An Apparatus for the Exact Analysis of Air in Metabolism Investigations with Respiratory Exchange Chambers. J. Metab. Res., Vol. 4, 1-25 (1923).

[19] Carpenter, T. M., Fox, E. L., Sereque, A. F.: The Carpenter Form of the Haldane Gas Analysis Apparatus. Changes Made in the Apparatus and Details Regarding its Use. J. Biol. Chem., Vol. 83, 211-230 (1929).

[20] Carpenter, T. M., Lee, R. C., Finnerty, A. E.: Ein Apparat Für die exakte und schnelle Analyse der Gase aus einer Respirationskammer. Wissenschaftliches Archiv f. Landwirtschaft, Vol. 4 (1930).

[21] Atwater, W. O., and Rosa, E. B.: Report of the Storrs Agricultural Experiment Station, page 212 (1897). Cited by DuBois, E. F., in Basal Metabolism in Health and Disease, 2nd edition, Lea and Febiger, page 81, 1927.

[22] Armsby, H. P., Fries, J. A., and Braman, W. W.: The Carbon Dioxide: Heat Ratio in Cattle. Nat. Acad. Sci. Proc., Vol. 6, 263-265 (1920).

[23] Bauer, V., and Blunt, K.: Effect of a Small Breakfast on the Energy Metabolism of Children. J. Biol. Chem., Vol. 59, 77-82 (1924).

[24] Marsh, M. E.: The Character of Energy Metabolism During Work. J. Nutr., Vol. 1, 57-89 (1928).

[25] Levine, S. Z., and Wilson, J. R.: The Respiratory Metabolism in Infancy and in Childhood. I. Basal Metabolism of Children. Am. J. Dis. Child., Vol. 31, 323-334 (1926).

[26] Wilson, J. R., Levine, S. Z., and Rivkins, H.: The Respiratory Metabolism in Infancy and in Childhood. II. Ketosis and the Respiratory Exchange in Children. Am. J. Dis. Child., Vol. 31, 335-356 (1926).

[27] Zuntz, N., and Schumburg, H.: Physiologie des Marches, Berlin, page 361 (1901). Cited by Carpenter, T. M., in Tables, Factors, and Formulas for Computing Respiratory Exchange and Biological Transformations of Energy, 2nd edition, Carnegie Inst. Washington, Pub. No. 303A, page 104, 1924.

[28] Langworthy, C. F., and Barott, H. G.: Energy Expenditure in Sewing. Am. J. Physiol., Vol. 59, 376-380 (1922).

[29] Benedict, F. G., and Johnson, A.: The Energy Loss of Young Women During the Muscular Activity of Light Household Work. Proc. Philos. Soc., Vol. 58, 89-96 (1919).

[30] Benedict, F. G.: Physical Factors in Predicting the Basal Metabolism of Girls. Proc. Am. Philos. Soc., Vol. 63, 25-56 (1924).

[31] Dreyer, G.: The Normal Basal Metabolism in Man, and Its Relation to the Size of the Body and Age, Expressed in Simple Formulæ. Lancet II, 289-291 (1920).

[32] Blunt, K., Tilt, J., McLaughlin, L., and Gunn, K. B.: The Basal Metabolism of Girls. J. Biol. Chem., Vol. 67, 491-503 (1926).

[33] Klugh, G. F.: Basal Metabolism in Normal Children from Six to Twelve Years of Age. J. Am. Med. Assoc., Vol. 91, 202 (1928).

[34] Wang, C. C., Kern, R., Frank, M., and Hays, B.: Metabolism of Undernourished Children. Am. J. Dis. Child., Vol. 32, 350-359 (1926).

[35] Schadow, H.: Gaswechseluntersuchungen im Kindes- und Pubertäts-alter. Monats. f. Kinderh., Vol. 34, 145-158 (1926).

[36] Kestner, O., and Knipping, H. W.: Die Ernährung des Menschen, Julius Springer, Berlin, 1926.

[37] Rosenblüth, A.: Der Grundumsatz bei Kindern und Jugendlichen. Zeit. f. Kinderh., Vol. 46, 531-547 (1928).

VITA

Martha Potgieter was born in Steamboat Rock, Iowa, November 25, 1899. She was educated in the public schools of Steamboat Rock, Iowa, attended Iowa State Teachers College two years and Central Iowa Business College two years, and taught commerce in the Eldora, Iowa, high school for four years (1923-1927). She attended the State University of Iowa 1927-1930, where she received the degree of Bachelor of Arts in chemistry and the degree of Master of Science in biological chemistry. While a graduate student there she was part-time assistant in the chemistry department of the University. She was a Lydia C. Roberts Fellow at Columbia University 1930-1932, majoring in nutrition under the Joint Committee on Graduate Instruction.

She was co-author with Dr. C. P. Berg of a paper entitled "Tryptophane Metabolism. II. The Growth-promoting Ability of *dl*-Tryptophane," published in the J. Biol. Chem., **94,** 661-673 (1932).